control of salinity

Thanks to David Hall, from LWTL
General Idea

- The objective is to keep the salinity close to a **setpoint** which will be provided by your instructor
- The salinity sensor measures the analog voltage output of the salinity circuit
- Opening DI solenoid valve decreases salinity
- Opening salty solenoid valve increases salinity

0.05 wt % NaCl \leq \text{setpoint for salinity} \leq 0.15 \text{ wt% NaCl}

*(your instructor will provide a setpoint, such as 0.09 wt% NaCl)*
Control of Salinity

$t_1 > t_2$ since valve is left open an amount of time proportional to the error.
key points

• The valve is left open an amount of time that is proportional to the error.
  • small error = valve is open a short amount of time
  • large error = valve is open a long amount of time

• The DI valve is left open longer than the salty valve when correcting for the same magnitude of error (DI=0%, setpoint = 0.09%, salty = 1%).

• The system has memory . . . it takes time for the salinity of the water to become uniform (mixing, water in pump and tubing). The lag time is called hysteresis.

• Control is more stable if we wait for the system to stabilize after opening a valve. The deadtime compensation is set to allow the system to come to equilibrium before responding to error.

• The upper and lower control limits are set so that random error will not cause the valves to open unnecessarily; these limits are often set three standard deviations of the error away from the setpoint. The difference between UCL and LCL is called the deadband.
control strategy

• The setpoint concentration will be assigned by your instructor. Assume 0.09% NaCl here.

• Compute the setpoint, UCL and LCL values for control of salinity (in analog reading units – between 0 and 1023):
  • Convert setpoint value from salinity concentration to analog output value using reverse curve fit equation
  • To compute UCL and LCL values, use the greatest standard deviation ($\sigma$) computed from calibration data.
    • $UCL = sepoint + 3\sigma$
    • $LCL = sepoint - 3\sigma$

• Using this approach, 99.7% of random error will fall between the LCL and UCL, which means that your solenoid valve will be triggered due to a false alarm only 0.3% of the time.

• UCL and LCL will therefore have the same units as analog output. (between 0 and 1023).
setting UCL and LCL by examining random error

Example Readings to Illustrate Procedure

<table>
<thead>
<tr>
<th>reading</th>
<th>analog output</th>
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<tbody>
<tr>
<td>0</td>
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<td>19</td>
<td>503</td>
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<td>20</td>
<td>504</td>
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</table>

mean = 503
standard deviation = 2.81
3 * standard deviation = 8.43

- \( UCL = \text{setpoint} + 3\sigma = 503 + 8 = 511 \)
- \( LCL = \text{setpoint} - 3\sigma = 503 - 8 = 495 \)

reading done at 0.09% salt concentration. This was the reading with maximum standard deviation for that particular fishtank.
setting deadtime compensation

- It takes time for your system to settle out after the salinity changes.
- Assume the system whose response is depicted in the graph below is “upset” at 18 seconds due to a sudden addition of salty water.
- At about 30 seconds, the salinity values stabilize (with continued random error at the new salinity level).
- For this example, the deadtime compensation would be set to 12 seconds (30s - 18s).
- This means that you would want to allow 12 seconds between salinity corrections.
strength of response to error

- We will compute the amount of salty water that should be added to the current mixture to correct the salinity.

- Over correcting repeatedly causes the system to oscillate about the setpoint.

- A correction that is too strong was applied.

- A second correction is applied – this one is also too strong.

- Over correcting repeatedly causes the system to oscillate about the setpoint.
apply a response proportional to error

- We will compute the amount of salty water that should be added to the current mixture to completely correct the salinity.
- We will open the solenoid valve long enough to remove a percentage of the error.
- For example, if the salinity is 0.152% and the setpoint is 0.09%, then applying an 80% correction will lower the salinity to 0.102%, which is computed as
  \[ \text{target} = (0.00152 - (0.00152 - 0.0009) \times 0.8) = 0.102 \% \]
- We call the proportionality constant the gain, \( G \); gain is a common term used when working with industrial controllers. Here \( G = 0.8 \).
Compute target concentration

More generally:

$$target = setpoint + (1-G)(salinity_{\text{initial}} - setpoint)$$
Assume that your fishtank system has a setpoint of 0.09% NaCl. Your instructor comes by your table and upsets your system by adding a good dose of DI water. The conductivity circuit returns an analog output that corresponds to a salinity of 0.04% NaCl (which is below LCL).

a) What is the target concentration if you have a gain of 0.80 (80%)?
b) Using this gain, how much salty water (1% NaCl) should be added?
c) How long should you leave the valve open if the flow rate is 0.2L/min?

Recommended assumptions:
The water that leaving at the overflow is a mixture of water from the salty tank and the fishtank.
The most salty the overflow water can be is 1% NaCl, and the least salty it can be is 0.04% NaCl. Assume that F=15% of the overflow water is 1% NaCl and that the rest is 0.04% NaCl.
Neglect density differences between incoming and outgoing water; that is, the mass of water that comes in from the salty tank is equal to the mass of water that leaves through the overflow.
sketch control structure

• Compute setpoint, using reverse curve fit equation

• Compute UCL and LCL

\[ UCL = \text{setpoint} + 3\sigma \]
\[ LCL = \text{setpoint} - 3\sigma \]

• Measure salinity to get analogS (the analog output of the conductivity circuit)

• If analogS > UCL or < LCL & if time since last correction > deadtime then . . .
  • Compute the %wt NaCl (using normal curve fit) to update LCD panel
  • Compute the target salinity based on your gain
    \[ \text{target} = \text{setpoint} + (1-G)(\text{salinity}_{\text{initial}} - \text{setpoint}) \]
  • Compute the time that your salty or DI solenoid valves needs to be left open
  • Open the DI or salty valve for the computed time